display or the nature of the suspension, or both, but the cells must be at least greater than the dimensions of the particles of electrophoretic material in the suspension.

By dividing the suspension layer into a plurality of cells or units a more uniform or sharply defined display can be produced because movement of the electrophoretic material is confined to the limits of each cell. Suspension material in different cells of the same assembly may emit light of different colour. The suspension units are preferably disposed between electrodes, one of which has a plurality of segment electrodes as shown at E_1, E_2, E_3, ... in Figure 12b corresponding to and in contact with the suspension in the individual cells, the other electrode being transparent and extending over the transparent wall 24 of the housing, also as shown in Figure 12b. If the cells are very numerous, the electrode E_1, E_2, E_3, etc. can be formed as dots. In this way, each cell with its portion of the suspension layer between an electrode segment and the common electrode forms an individually controllable picture element Each cell can be caused to produce a colour image by applying a direct viltage between the common electrode 28 and the selected segment electrode while the suspension layer units are exposed to radiation flux.

One way to provide electrodes for a number of such cells which are in an orderly pattern is to provide a first electrode structure consisting of a plurality of strip electrodes parallel to each other and a second electrode consisting of a plurality of strip electrodes which are disposed at right angles to the strips of the first electrode, similar to the arrangement shown in Figure 7. The cell located at each intersection of a strip of the first electrodes and a strip of the second electrodes can then be selectively activated, and can be used as a picture element. The cells can then, by use of a suitable suspension, be arranged to emit different colour light, for example red light as at 50R, green light as at 50G, or blue light as shown at 50B in Figure 12c. The production of a suitable electric field by appropriate voltages impressed on the electrodes can be arranged to cause selected picture elements to reproduce a luminescent coloured image on the display panel.

A display panel for producing a colour image can be provided by using mosaic colour filters and a suspension capable of changing in shades of grey between black and white; areas of the transparent wall of the housing or the transparent electrode corresponding to each picture element in a display panel of the type shown in Figures 7 or 12b are selectively coloured so that it acts as a colour filter, for example, for red, green or blue. However, a display device having at least three kinds of suspensions, that is red, green and blue, gives a better colour rendering, especially with respect to the brightness of the high lights, than can a panel with the mosaic colour filter on the transparent wall or electrode.

A monogrammatic character display panel, similar to that described with reference to Figure 6, can also be formed by a series of individual units each corresponding to one of the segmental electrodes shown.

It is not necessary that the suspension layer should be defined by plane surfaces, and curved surfaces can be used. For example, in Figure 14, the suspension layer 50 is enclosed in a housing consisting principally of two concentric cylinders 75 and 76. The inner cylinder 75 carries an electrode 79 and cylinder 76 an electrode 78 attached thereto. Electrodes 79 and 78 are similar in nature to electrodes 52 and 53. The cylinder 75 can be constructed to enclose a gas such as, for example, argon or krypton and mercury capable of sustaining a gas discharge. With the gases mentioned, ultra-violet radiation, mainly at 2537Å, is emitted if an electric field is applied to the gas in conditions to cause a suitable discharge.

The inner cylinder and the electrode attached to the outer surface of the cylinder are transparent to the radiation flux. The outer cylinder and the electrode on its inner surface are transparent to visible light. A direct voltage from a voltage source 30 is applied between the electrodes so as to control the spatial distribution of the electrophoretic material of the suspension and thereby the luminescent appearance of the device. The source 30 can supply not only the direct voltage but also said electric field, such as an alternating field for producing the gas discharge. The inner surface 101 of the inner cylinder can have upon it a coating of fluorescent material to convert the light in the ultra-violet spectrum from the gas discharge into radiation in other parts of the spectrum. The device in Figure 14 is useful as a fluorescent lamp, the colour of which can be changed by varying the intensity, duration time of application and the polarity of applied direct voltage.

The amount of electrophoretic material in a suspension medium or the thickness of the electrophoretic suspension layer is selected, depending upon the opacity, luminescent property or electrophoretic property of the electrophoretic material, the range of colour change required in the device, feasibility of the voltage souce and so on.

Since the display devices described are of the luminescent type, a component of the suspension layer must be opaque with respect to the radiation flux and/or visible

light in order to make an adequate colour change. The thicker the suspension layer, the higher the applied voltage usually required. The thinner the suspension layer, the greater the concentration of electrophoretic material required for a given colour change. The thickness of the suspension layer in practical devices is usually in the range from a few microns to a few mm.

The following are examples of suitable material.

EXAMPLE 1

Ten grams of Cyanine green B particles, which is phthalocyanine green supplied by Dainippon Ink Chemical Industrial Company in Japan, were added to 100 ml of olive oil and blended well in a ball mill to produce a first paste. The first paste was deep green in colour when viewed in white light. The green particles had negative charge polarity in olive oil. Ten grams of a fluorescent powder particles supplied as EL-GSL by Sakai Chemical Industrial Company in Japan in a main body of zinc sulphide were added to 50 ml of olive oil and mixed well by ultrasonic vibration to produce a second paste. The second paste had a faint green colour when viewed in white light. The zinc sulphide particles had weak positive charge polarity and did not show any noticeable electrophoresic activity in olive oil. Equal volumes of the first and the second pastes were mixed well to produce a third paste. The third paste was placed between an aluminium plate and an EC glass electrode so to produce a luminescent electrophoretic suspension layer having a thickness of 100μ. The EC glass was a transparent glass plate having a transparent conductive layer of tin oxide thereon. The suspension layer radiated yellowish green light through the EC glass electrode when the suspension layer was exposed, through the EC glass electrode, to ultra-violet radiation flux from a black light lamp. When a direct voltage of 300 V was applied between the EC glass electrode as cathode and the aluminium plate as anode, the luminescent colour of the suspension layer changed and became bright green. When the polarity of the applied voltage was reversed, the colour of the suspension layer became deep green. The luminescent green colour of the suspension layer could be changed in brightness by varying the voltage, time of application or polarity of the applied voltage. The displayed colour could be maintained after the removal of the applied field. The reflective colour characteristic of the suspension layer could also change its green colour on application of a direct voltage when viewed under white light. The zinc sulphide particles used were electroluminescent and the suspension layer radiated electroluminescent light on application of an electric field.

A direct voltage of 300 V was applied between the EC glass electrode as cathode and the aluminium plate as anode. After that, when a sinusoidal alternating voltage of 250V at 1 kHz was applied between the two electrodes, the suspension layer emitted a bright green light through the EC glass. When the sinusoidal voltage was applied between the two electrodes after application of a direct voltage of reverse polarity, the suspension layer was deep green. As mentioned above, the suspension layer in this example radiated visible light when ultraviolet light or an alternating electric field was applied to it. The cell was useful as a colour change panel in which green brightness could be controlled.

EXAMPLE 2

Ten grams of fluorescent powder particles supplied as EL-RI by Dainippon Paint Company in Japan, in a main body of zinc sulphide was added to 50 ml of toluene dissolved ten grams of vinyl acetate resin therein and mixed well by application of ultrasonic vibration to produce a paste.

The surface of screen sheet No. 1000 supplied by the Teijin Company of Japan and woven of polyester fibre was coated with the paste to produce a luminescent porous layer. The porous layer emitted red light when exposed to ultraviolet light from a black light lamp. Five grams of the fluorescent powder particles as used in Example 1 were added to 50 ml of isopropyl alcohol and mixed well by an ultrasonic vibrator to produce a suspension. The powder particles had negative charge polarity in isopropyl alcohol. The luminescent porous layer was inserted between two screen sheets No. 1350 supplied by Teijin Company of Japan to produce a sandwich; a housing was fashioned by inserting the sandwich between an EC glass electrode and an aluminium plate, and the housing was filled with the suspension to produce a luminescent electrophoretic suspension layer. The housing was made liquid-tight by an adhesive agent. When the suspension layer was exposed, through the EC glass electrode, to ultra-violet light from a black light lamp, the suspension layer emitted yellow light. When a direct voltage of 25V was applied between the EC glass electrode as anode and the aluminium plate as cathode, the luminescent colour of the suspension layer was green under ultra-violet light. Application of a direct voltage of reverse polarity between the EC glass electrode and the aluminium plate changed the luminescent colour of the suspension layer from green, through yellow, to red. A sinusoidal

alternating voltage of 150 V and 60 Hz was half-wave rectified by a rectifier so as to produce repeated unidirectional pulses of voltage and when this pulse voltage was applied between the EC glass electrode and the aluminium plate, the suspension layer emitted electroluminescent orange light when the EC glass electrode was the cathode and green light when the glass was the anode.

The device of this example was useful as an electric colour changeable panel capable of being altered in colour from green, through yellow, to red and vice versa under excitation by ultraviolet light.

Attention is directed to our co-pending Applications 19611/70 and 19612/70 (Serial Nos. 1,313,412, 1,313,413) which contain claims directed respectively to devices and to methods of operating devices utilizing electrophoretic movement.

WHAT WE CLAIM IS:—

1. A display device comprising a layer, including a luminescent material, the luminescent appearance of the device being controllable by electrophoretic movement of an electrophoretic material in said layer.

2. A display device in accordance with claim 1, wherein said electrophoretic material is luminescent.

3. A display device in accordance with claims 1 or 2, and comprising a luminescent non-electrophoretic material.

4. A display device comprising a layer including a suspension medium and at least one material in a form susceptible of electrophoretic mobility suspended in said medium, at least one of the components of said layer being luminescent material, and at least one of the components of said layer being substantially opaque to the radiation which excites the luminescence or to visible light emitted by the luminescent component, said suspension being bounded by opposed surfaces, spaced electrodes positioned with respect of said surfaces whereby on applying an electric field across said layer between said electrodes, the spatial distribution of said electrophoretic material between said surfaces is electrophoretically changed whereby to change the luminescent appearance of said device.

5. A display device in accordance with claim 4, wherein said surfaces are generally parallel.

6. A display device in accordance with claim 5, wherein electrodes are positioned to impose on said suspension a field which is substantially at right angles to the said surfaces.

7. A display device in accordance with claims 4, 5 or 6, wherein at least one electrode is positioned on one of said surfaces.

8. A display device in accordance with any of claims 4 to 7 wherein a wall member defining at least one of said surfaces is transmissive to energy for exciting said luminescent material.

9. A display device in accordance with any of the preceding claims, wherein said luminescent material is capable of being rendered luminous by electromagnetic radiation.

10. A display device in accordance with claim 9, wherein said radiation is in the non-visible spectrum.

11. A display device in accordance with claim 10, wherein said radiation is in the ultra-violet range.

12. A display device in accordance with any of the claims 4 to 8, wherein said radiation is energy from a radioactive source.

13. A display device in accordance with claim 12, wherein said source is an embodied part of said display device.

14. A display device in accordance with claim 13, wherein said source is in said suspension.

15. A display device in accordance with claims 12, 13 and 14, wherein said energy is radiation from a radioactive isotope of radium, strontium 90, tritium or promethium 147.

16. A display device in accordance with any of claims 4 to 15 comprising means for applying a voltage between said electrodes.

17. A display device in accordance with claim 16, and comprising means for impressing an alternating electric field on said layer.

18. A display device in accordance with claim 16, and comprising means for impressing a repetitive uni-directional pulse field on said layer.

19. A display device in accordance with any of claims 4 to 18, wherein at least said electrophoretic material is luminescent.

20. A display device in accordance with any of the preceding claims and comprising at least two electrophoretic materials, which differ in charge polarity.

21. A display device in accordance with any of claims 1 to 19, and comprising at least two electrophoretic materials, which differ in electrophoretic mobility.

22. A display device in accordance with any of the preceding claims, and comprising at least two electrophoretic materials which differ in luminescent properties.

23. A display device in accordance with any of claims 4 to 22 wherein said suspension medium is luminescent.

24. A display device in accordance with any of claims 4 to 23 and comprising a porous layer inserted in said suspension medium.

25. A display device in accordance with claim 24 wherein said porous layer is luminescent.

26. A display device in accordance with any of claims 4 to 25, wherein said suspension further contains a binder for said electrophoretic material, which binder is at least partially soluble in said suspension medium.

27. A display device in accordance with any of claims 4 to 26, wherein said suspension medium is a hardenable material.

28. A display device in accordance with claim 27, wherein said suspension medium is heat hardenable.

29. A display device in accordance with any of claims 4 to 26 wherein said suspension medium is heat softenable.

30. A display device in accordance with any of claims 4 to 29, and including means for applying an electric field to said suspension and means for controlling said electric field as to intensity and/or duration and/or polarity.

31. A display device in accordance with any of the claims 4 to 30, and including a housing enclosing said layer, said housing presenting two spaced opposed major housing walls between which said suspension layer and said electrodes are positioned.

32. A display device in accordance with claim 31, wherein at least one wall and the adjacent electrode are transparent to visible light.

33. A display device in accordance with claim 32, wherein one electrode and the adjacent wall is transparent to energy, or radiation, inducing luminescence, and the other electrode and the other wall is transparent to visible light.

34. A display device in accordance with claim 33, wherein one of said walls is transparent with respect to said energy or radiation and has one electrode attached thereto, and the other of the walls is transparent with respect to visible light and has a second electrode attached thereto.

35. A display device in accordance with claim 32, wherein one of said walls and an adjacent electrode is transparent with respect to both said radiation and visible light.

36. A display device in accordance with any of claims 4 to 35, wherein at least one of said electrodes is in the shape of a desired pattern for display.

37. A display device in accordance with any of claims 4 to 35, wherein at least one of said electrodes is formed as a series of independent electrodes disposed on a common surface.

38. A display device in accordance with claim 37, wherein said electrode is formed as a series of substantially parallel strips of electrode material.

39. A display device in accordance with claim 38 wherein the other electrode is formed as a series of substantially parallel strips of electrode material.

40. A display device in accordance with claims 38 and 39, wherein the strips of the respective series are disposed substantially at right angles.

41. A display device in accordance with claim 37, and comprising means to define individual bodies of suspension pertaining to and controllable by said independent electrodes.

42. A display device in accordance with claim 41, wherein said individual bodies of suspension have different luminescent properties.

43. A display device in accordance with any of claims 4 to 42, wherein at least one said electrodes is provided with an insulating layer in contact with said suspension.

44. A display device in accordance with claim 32 wherein said transparent housing wall or said transparent electrode has a mosaic of colour filters thereon.

45. A display device in accordance with any of claims 4 to 44 and comprising cylindrical inner and outer walls confining said suspension.

46. A display device in accordance with claim 45, wherein the interior of said inner wall contains a gas, and comprising means for producing a luminous electric discharge in said gas.

47. A display device in accordance with any of the claims 4 to 46, said device being in association with an electron beam device, the beam current of which is adapted to control the electric field existing across said layer.

48. An improved display device, substantially as described, with reference to the accompanying drawings.

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1314906 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

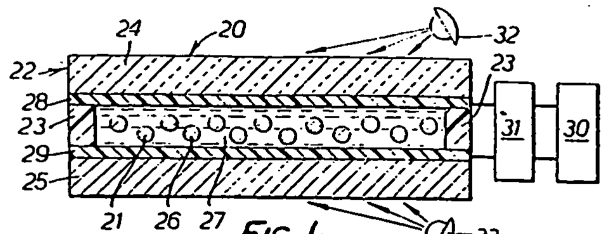

FIG. 1a.

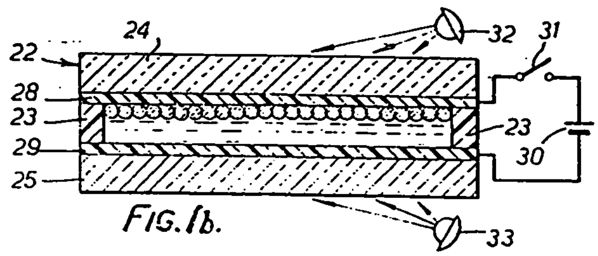

FIG. 1b.

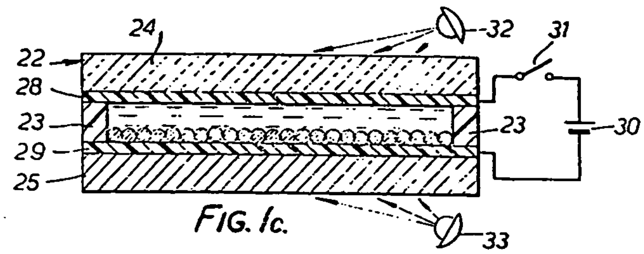

FIG. 1c.

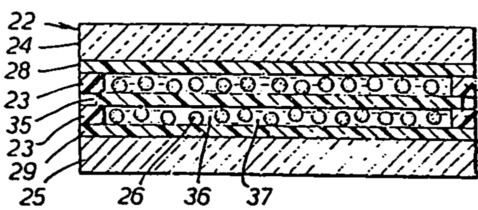

FIG. 2a.

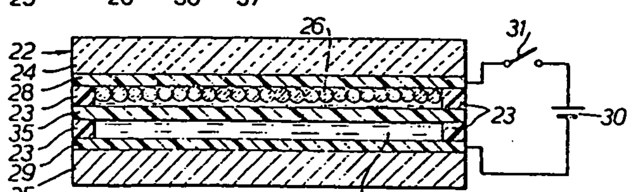

FIG. 2b.

1314906 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

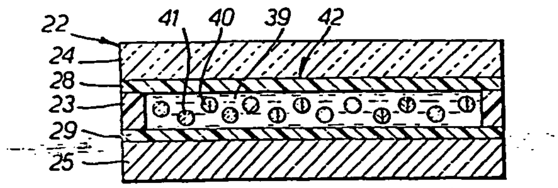

FIG. 3a.

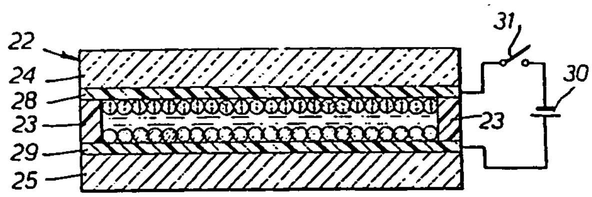

FIG. 3b.

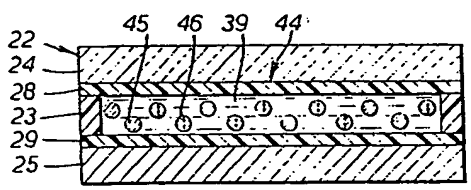

FIG. 4a.

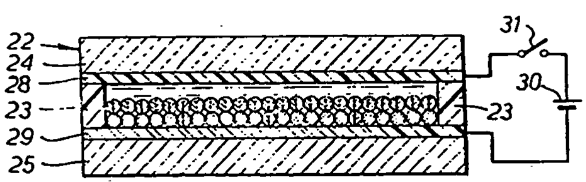

FIG. 4b.

1314906 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

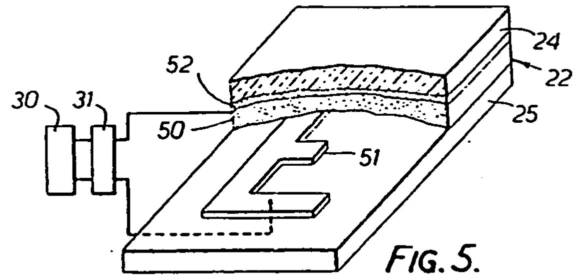

FIG. 5.

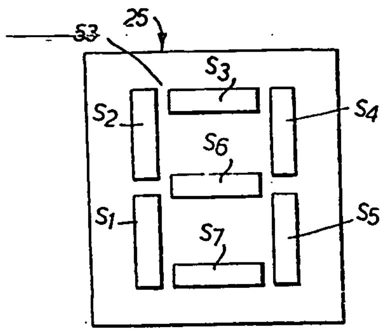

FIG. 6a.

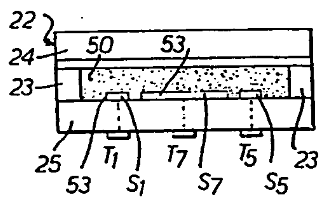

FIG. 6b.

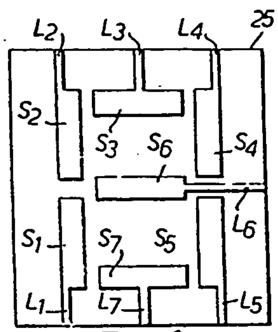

FIG. 6c.

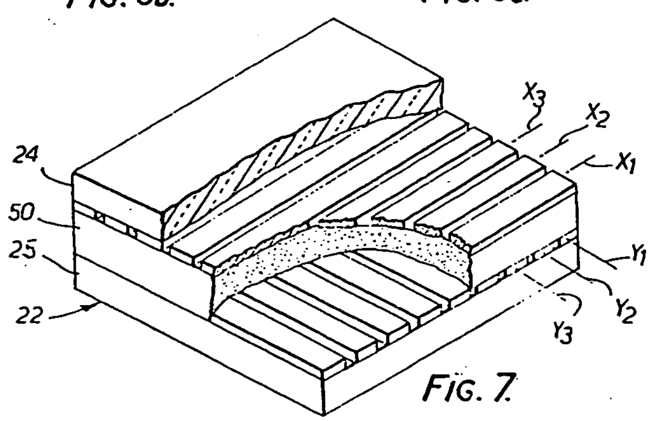

FIG. 7.

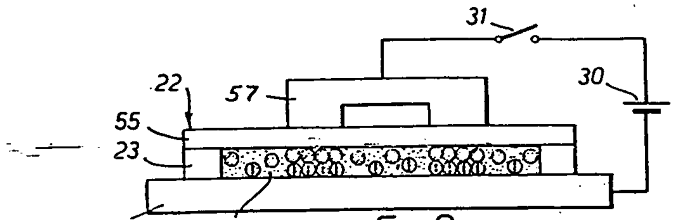

FIG. 8a.

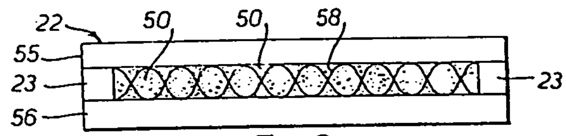

FIG. 8b

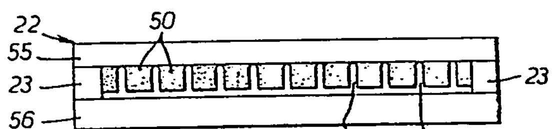

FIG. 8c

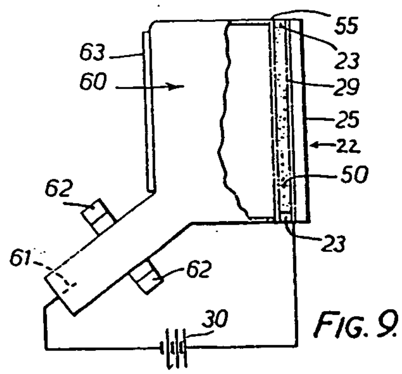

FIG. 9.

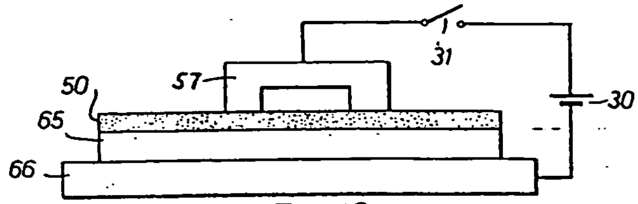

FIG. 10.

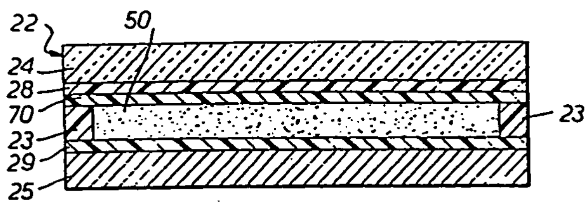

FIG. 11.

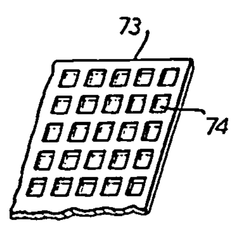

FIG. 13.

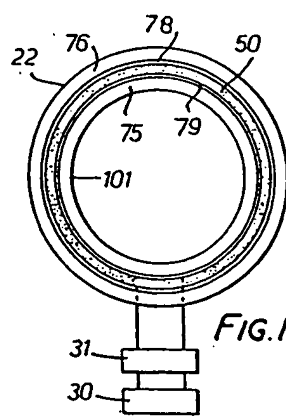

FIG. 14.

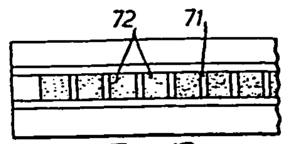

FIG. 12a.

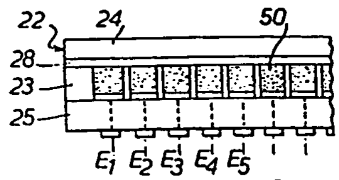

FIG. 12b.

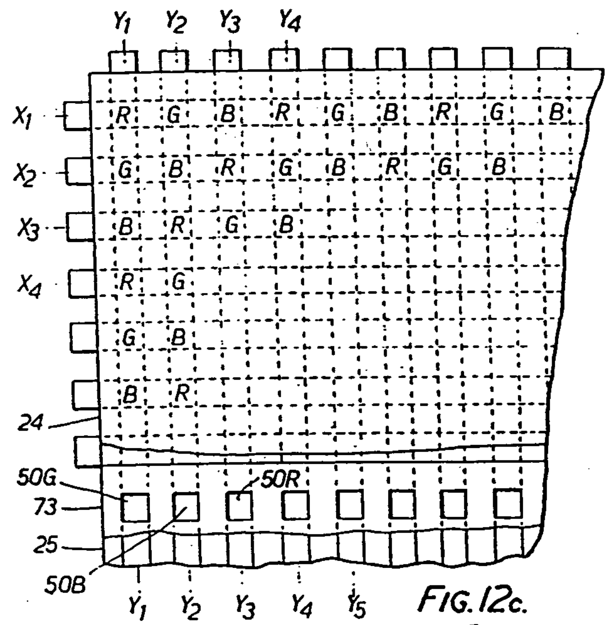

FIG. 12c.

B22

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1 465 701

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G2H 1H 1Y 5F2 5F3 5FY 5Y
G2F 23E 25F 25R CK

(19)

(72) Inventors PETER COLIN NEWMAN and ROY TREVOR BLUNT

(54) AN ELECTROPHORETIC SUSPENSION

(71) We, THE PLESSEY COMPANY LIMITED, a British Company of 2/60 Vicarage Lane, Ilford, Essex, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to working fluids for electrophoretic image reproduction devices.

According to the invention there is provided a working fluid for an electrophoretic image reproduction device including a dispersion of finely divided particles which exhibit electrophoresis, suspended in a suspension medium, each of the said particles including a body of an inactive organic compound at least partially surrounded by a layer of a dielectric material which is adapted to collect the required charge for effecting particle transportation, wherein the body effects a density match between the suspension medium and the said particles.

The said body can be impregnated with a dye, for example a fluorescent dye, which makes the body light reflective and with this arrangement the thickness of the dielectric layer would be arranged so that the layer is light transparent. Alternatively, the dielectric layer could be rendered light reflective, the said body being adapted to effect a density match between the suspension medium and the particle in both of these arrangements.

According to a preferred feature of the invention, a working fluid as outlined in a preceding paragraph is provided which also includes within the said body a core of a light reflective material, the said body being of a light transparent material which is adapted to effect a density match between the suspension medium and the particle. The core is preferably of magnesium although other suitable light reflective materials, for example hexagonal boron nitride and heavily-doped silicon could be used. Heavily doped silicon being silicon in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}, (Phys Rev *96* (1), 28—35 (1954). The said body can be of a polymer such as poly(acrylonitrile) or other organic compounds.

The dielectric layer can be of titanium dioxide (TiO_2) or other dielectric oxides such as SiO_2 or Al_2O_3 or hydrous forms of these oxides.

The foregoing and other features according to the invention will be better understood from the following description with reference to drawings accompanying the Provisional Specification, in which:

FIGURE 1 diagrammatically illustrates an electrophoretic image reproduction device in a cross-sectional side elevation,

FIGURE 2 diagrammatically illustrates in a cross sectional side elevation the structure of the electrophoretic particles of a working fluid according to the invention, and

FIGURE 3 illustrates contours of reflectivity (at normal incidence) for the interface between a semi-infinite sheet of material with a refractive index $n+ik$ and poly(acrylonitrile).

An electrophoretic image reproduction device is diagrammatically illustrated in FIGURE 1 of the drawings in a cross-sectional side elevation and includes a working fluid 1 enclosed in a housing 2 consisting of a hollow open-ended plastics container 3 closed at each end by transparent electrically insulating members 4 and 5, for example of glass, polyester, cellulose acetate, regenerated cellulose or polyethylene. Transparent electrodes 6 and 7, for example, of cuprose oxide or tin oxide, are respectively attached to the inner surfaces of the members 4 and 5 and are in contact with the electrophoretic suspension medium 1.

The working fluid 1 includes a dispersion of finely divided particles *1b* which exhibit electrophoresis, suspended in a suspension medium *1a* such as isopropyl alcohol or olive oil. The particles *1b* are shown greatly enlarged for the sake of clarity but, in practice, it is thought that the particles *1b* must not be greater than 1/10 of the spacing between

the electrodes 6 and 7.

In operation, the electrodes 6 and 7 are connected to a direct voltage source (not illustrated), the polarity of which can be reversed. In the absence of an electric field between the electrodes, the particles 1*b* are, as is illustrated in FIGURE 1, distributed uniformly throughout the suspension medium 1*a*. If, for example, the particles 1*b* are white and the suspension medium 1*a* is black, the working fluid 1 will, in the absence of an electric field, appear grey when illuminated by an incandescent lamp. When the grey working fluid is subjected to a unidirectional electrical field as a result of the application of the direct voltage source to the electrodes 6 and 7, the particles 1*b* are caused to move electrophoretically in the direction either of the cathode electrode or the anode electrode depending on the polarity of their charge. If, for example, the particles 1*b* acquire a negative charge and the electrode 6 is the anode electrode, then the particles 1*b* will migrate towards, and will be deposited on the surface of, the electrode 6. Under these conditions spatial distribution of the particles 1*b* in the suspension medium 1*a* will be different from the initial uniform distribution illustrated in FIGURE 1 and, therefore, the working fluid 1 will have different optical reflectance properties from those of the original working fluid illustrated in FIGURE 1. With the exampled working fluid given above, the electrophoretic image reproduction device will, under these conditions appear white at the surface 2*a* and black at the surface 2*b*.

The colour appearing at the surfaces 2*a* and 2*b* of the image reproduction device of FIGURE 1 can be reversed by reversing the polarity of the voltage that is applied between the electrodes 6 and 7.

The particles 1*b* used in the working fluid 1, are, therefore, required to fulfil three quite separate functions in that the particles must be able to (a) scatter light efficiently, (b) match the density of the suspension medium 1*a* and (c) have a high mobility, which in turn means a high zeta potential.

In a working fluid according to the invention these three functions are fulfilled by utilising electrophoretic particles having, as is diagrammatically illustrated in FIGURE 2 of the drawings in a cross-sectional side elevation, a three-layered structure.

The function (a) will be effected by the core 8 which must, therefore, be formed from a light reflective material, the function (b) will be effected by a layer 9 of a light, transparent plastics material which surrounds the core 8 and the function (c) will be effected by a layer 10 of a dielectric material which is formed on the surface of the plastics layer 9.

A list of materials that may be suitable for the core 8 are given in the following table. All the materials have a density value less than 3.0, the optical constants n and k refer to the complex refractive index $n+ik$ and the optical constant R refers to material reflectivity and is given by the formula:

$$R = \frac{(n-n_o)^2 + k^2}{(n+n_o)^2 + k^2}$$

Material	Material Density	Optical Constants		
		n	k	R (observed)
B_2S_3	1.55			
Mg	1.74		2–4	~0.72
Be	1.85			
Mg_2Si	1.94	3½–5	0–2	0.35–0.65
Al_2S_3	2.02			
Mg_3P_2	2.06			
BP	2.08			
BN (hex)	2.25			
Si	2.33	3¾–5	0	0.33–0.45
B	2.34, 2.37			
BeS	2.36			
B_2O_3	2.46	1.62		
Al	2.70		2¼–6	~0.70
Mg_3N_2	2.71			
MgS	2.84	2.27		
AlP	2.85	3.4		

The choice of a material for the core 8 is dependent on factors such as availability, ease of manufacture and cost. From the list of materials which is by no means exhaustive, the three materials that are easily available and ideally suited for the core of the electrophoretic particles 1*b* are magnesium, hexagonal boron nitride and heavily-doped silicon, i.e. silicon in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}.

The plastics layer 9 can be of a polymer such as poly(acrylonitrile) for which n_o = 1.51 and k_o = 0.

FIGURE 3 illustrates contours of reflectivity (at normal incidence) for the interface between a semi-infinite sheet of material with a refractive index $n+ik$ and poly(acrylonitrile). The reflectivity contours for the core 8/layer 9 construction of FIGURE 2 will be somewhat different to the contours of FIGURE 3, but these contours a reconsidered to be adequate for first- order selection.

It can be seen from FIGURE 3 that, for really high values of reflectivity, it is more important to have high values of k than of n and for this reason the preferred material for the core 8 is magnesium.

In another working fluid according to the invention the three-layered structure of FIGURE 2 is replaced by a two-layered structure, the layer 9 and the core 8 being replaced by a single body of an inert polymer or other organic compound which is surrounded by the dielectric layer 10 of FIGURE 2.

The function (b) referred to in a preceding paragraph will be effected by the single body of the two-layered structure and the function (c) will, as with the structure of FIGURE 2, be effected by the dielectric layer.

In one arrangement of the two-layer structure, the single body is impregnated with a dye, for example a fluorescent dye which makes the body light reflective and thereby

adapted to effect the function (a) referred to in a preceding paragraph. With this arrangement the thickness of the dielectric layer would be arranged so that the layer is light transparent.

In an alternative arrangement of the two-layered structure the function (a) is effected by the dielectric layer which would be of a thickness that substantially prevents light transmission therethrough.

The single body of the two-layered structure can be of either poly(acrylonitrile), or polyethylene, or poly(trimethylpentene).

The dielectric layer which can be formed from titanium dioxide TiO_2, or other dielectric oxides such as SiO_2, or Al_2O_3 or hydrous forms of these oxides, must be such that sufficient charge can be collected for effecting particle transportation in the suspension medium 1*a*. It is thought that it may not be necessary for the dielectric layer to be formed in a continuous layer.

Since the dielectric layer will be deposited on a polymer during the production of the particles 1*b*, it will be necessary, during deposition of the dielectric layer, to utilise low temperature reactions such as the hydrolysis of isopropoxides or chlorides, for example,

$$Al(OC_3H_7)_3 + 3H_2O \rightarrow Al(OH)_3 + 3HOC_3H_7$$

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$$

It is to be understood that the foregoing description of specific examples of this invention is made by way of example only and is not to be considered as a limitation in its scope.

WHAT WE CLAIM IS:—

1. A working fluid for an electrophoretic image reproduction device including a dispersion of finely divided particles which exhibit electrophoresis, suspended in a suspension medium, each of the said particles including a body of an inactive organic compound at least partially surrounded by a layer of a dielectric material which is adapted to collect the required charge for effecting particle transportation, wherein the body effects a density match between the suspension medium and the said particles.

2. A working fluid as claimed in claim 1 wherein the said body is impregnated with a dye which makes the said body light reflective and wherein the thickness of the dielectric layer is arranged so that the layer is light transparent.

3. A working fluid as claimed in claim 2 wherein the dye is a fluorescent dye.

4. A working fluid as claimed in claim 1 wherein the dielectric layer is light reflective.

5. A working fluid as claimed in claim 1 which also includes within the said body a core of a light reflective material, the said body being of a light transparent material which is adapted to effect a density match between the suspension medium and the particle.

6. A working fluid as claimed in claim 5 wherein the core is of magnesium.

7. A working fluid as claimed in claim 5 wherein the core is of either hexagonal boron nitride or silicon, in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}.

8. A working fluid as claimed in any one of the preceding claims wherein the said body is of either poly(acrylonitrile), or polyethylene, or poly(trimethylpentene).

9. A working fluid as claimed in any one of the preceding claims wherein the dielectric layer is of either TiO_2, or SiO_2, or Al_2O_3, or hydrous forms of these oxides.

10. A working fluid for an electrophoretic image reproduction device as claimed in claim 5 substantially as hereinbefore described with reference to the drawings accompanying the provisional specification.

11. A working fluid for an electrophoretic image reproduction device as claimed in claims 1 to 4 substantially as hereinbefore described.

12. An electrophoretic image reproduction device which includes a working fluid as claimed in any one of the preceding claims.

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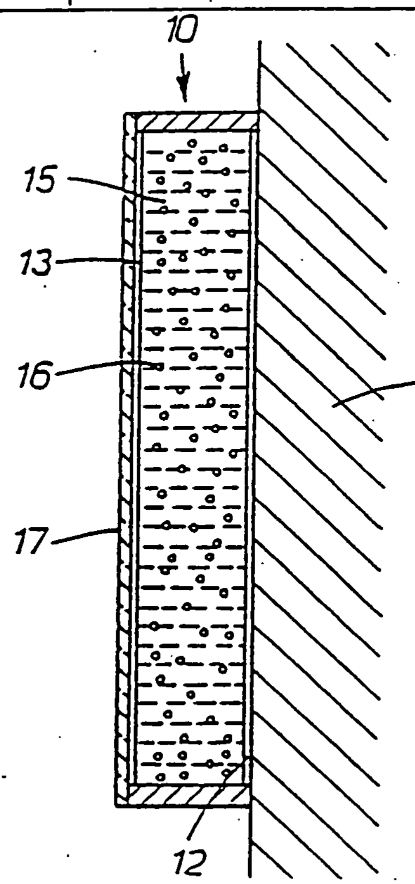
(54) Title: DISPLAY DEVICE

(57) Abstract

An electrophoretic display device utilizes transparent spheres (16) whose diameter is similar to that of visible light in place of the conventional pigment particles whereby to enhance the retro-reflective effect of the device. The spheres (16) may be glass or plastics or a combination of both with a specific gravity similar to that of the suspension medium (15) in which they are contained.



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DISPLAY DEVICE

The present invention relates to display devices and more particularly to electrophoretic or dielectricphoretic display devices.

Electrophoretic display devices are known and a feature of these devices is that they are passive, i.e. they do not emit light rather they reflect or transmit incident light.

An object of the present invention is to provide an electrophorectic or dielectricphoretic display device with enhanced reflectance in the direction of illumination.

In order that the present invention be more readily understood, an embodiment thereof will now be described by way of example with reference to the accompanying drawing which shows a cross-section through an electrophoretic display device.

An electrophoretic display device 10 comprises a non-conductive substrate 11 to which is applied an electrode 12 and an electrode 13 spaced from the electrode 12. The space between the electrode 12 and the electrode 13 is filled by a liquid material 15 containing small particles 16. When an electric field is applied across the space by a voltage applied to the electrode 12 and electrode 13, the particles migrate to either the electrode 12 or the electrode 13. Either or

both of the electrodes 12, 13 can be an array so as to produce any desired pattern depending on the disposition and shape of the or each array.

In this embodiment, the device is designed for viewing in the direction of the arrow A in which case the electrode 13 will be formed of a transparent material and provided with a transparent protective cover 17.

The particles 16 are specifically selected for their reflective properties and it has been found that they should be optically transparent in at least part of the visible spectrum. Further, they should have a diameter similar to or larger than the wavelength of visible light, e.g. from 0.5 to 20 microns. It is advantageous if they have a specific gravity similar to that of the liquid material so that they exhibit neutral buoyancy in the liquid material and can move relatively easily under the action of an electric field.

These two desiderata point to glass or plastics particles being used. A combination of glass and plastics is also possible such as glass coated with plastics. The preferred plastics are polyamide, polyimide, polyester, polypropylene or polycarbonate.

Preferably the particles are spherical but may be either solid or hollow spheres. The refractive index of the material of the spheres should preferably be higher than that of the liquid material. Such particles are known to exhibit good reflectance in the direction of illumination.

The electrophoretic activity can be enhanced by adding a surfactant to the liquid material and/or by forming electrets within the particles.

The above construction may be used as an addressable sign such as a road sign, a warning display or an information panel and has the additional advantages that dye absorption on reflective glass particles would

be lower than absorption on conventional organic pigments. This provides increased perceived contrast. Also, chemical and light-induced degradation is lower for glass particles than for organic pigments. Thus, the life of the device would be increased.

With glass particles, it may be necessary to process them so that they exhibit an electrophoretic effect. A number of processes are available such as exposing molten glass to an electrical discharge and cooling the glass to trap charged particles in the glass matrix. Alternatively, glass at room temperature could be exposed to ionizing radiation such as cathode rays or X-rays to form charged particles in the glass. Both these processes form electrets but it is also possible to activate the surface of the glass particles chemically and then coat the particles with long chain molecules to cause a charge to be present.

CLAIMS:

1. A display device comprising spaced electrodes and electrophoretically active particles in a liquid suspension medium disposed between said electrodes, the particles having a refractive index greater than that of the suspension medium characterised in that the particles are transparent to light in at least part of the visible spectrum and have an external diameter similar to or larger than the wavelength of visible light.

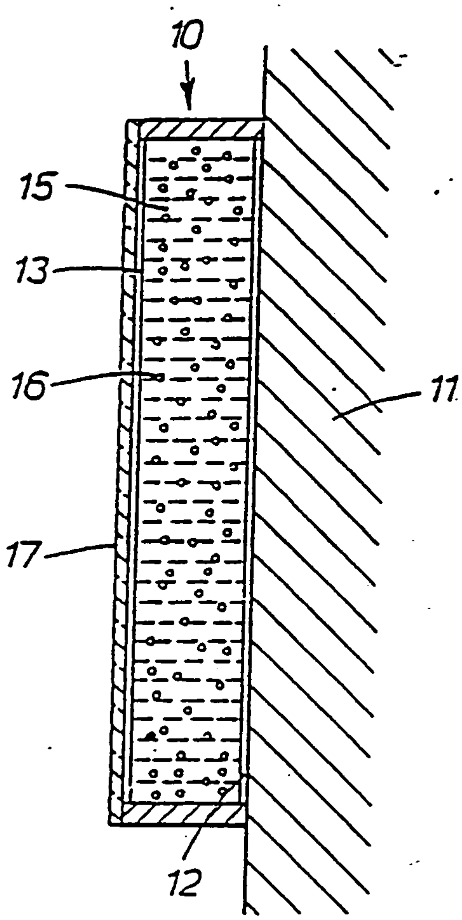
2. A display device according to claim 1, characterised in that the particles are spheres and are of glass or plastics materials or a combination thereof.

3. A display device according to claim 1 or 2, characterised in that the particles are hollow.

4. A display device according to claim 1, 2 or 3, characterised in that the particles have a specific gravity similar to that of the suspension medium.

5. A display device according to any one of the preceding claims characterised in that the particles include electrets to enhance the electrophoretic activity.

6. A display device according to any one of the preceding claims, characterised in that the liquid suspension medium includes a surfactant to enhance the electrophoretic activity.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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category*	Citation of Document,[16] with indication, where appropriate, of the relevant passages[17]	Relevant to Claim No[18]
	"Developments in electrophoretic displays", see pages 243-254, in particular page 244, paragraph B and page 245, paragraph III	1,6
A	US, A, 2792752 (A.J. MONCRIEFF-YEATES et al.) May 21, 1957, see column 4, line 24 and claim 1	1,2
A	US, A, 3972715 (K. OKUMURA) August 3, 1976, see column 6, lines 18-20 and claim 1	5
A	Optics Communications, volume 15, no. 2, October 1975 (Amsterdam, NL) T. Yoshimura et al. "The spectral profile of light scattered by particles in electrophoretic movement", see pages 277-280	2
A	GB, A, 1442360 (SECRETARY OF STATE FOR DEFENCE) July 14, 1976	1,2
A	US, A, 3169163 (H. Nassenstein) February 9, 1965	1
A	US, A, 3782932 (V. TULAGIN) January 1, 1974	1